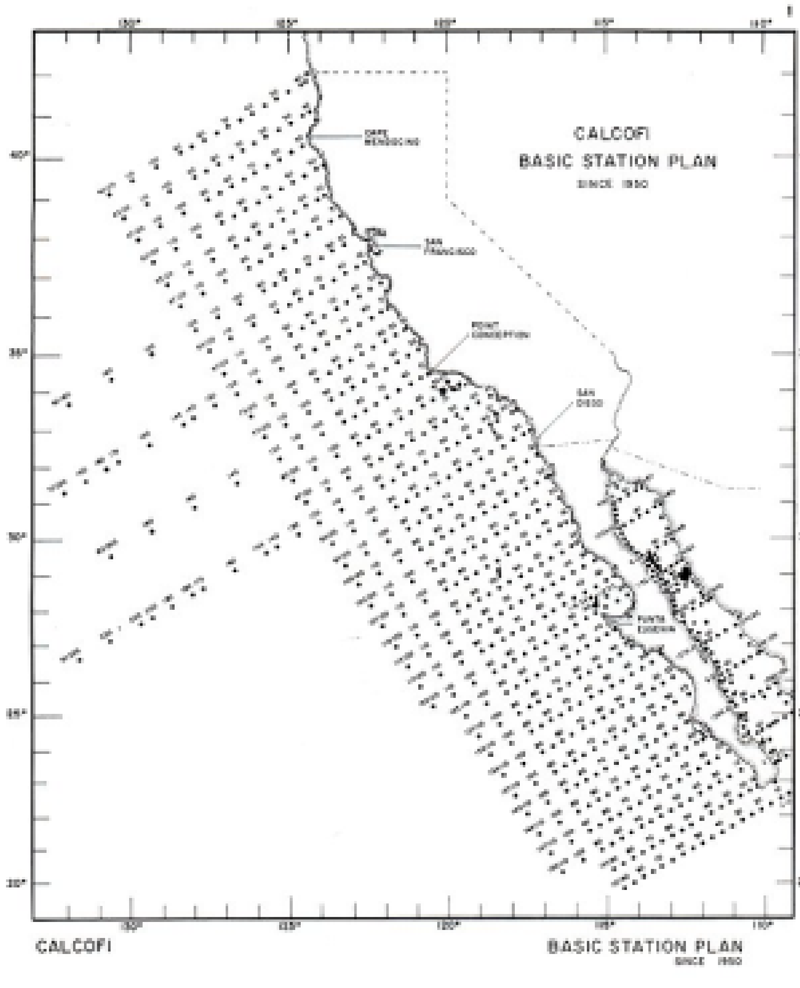
Comparing Computed Geostrophic Currents with ADCP Measurements along CALCOFI Line 67



LT David Blencoe

OC3570 Winter Cruise, Feb 2001

A. INTRODUCTION

The California Current flows south along the west coast of North America, extending from the Columbia River to central Baja California (MacCall, 1986). It forms the eastern portion of the North Pacific Subtropical Gyre, flowing equatorward off the western United States and northern Mexico, displaying a mixture of filaments, mesoscale eddies, and counterflows (Bakun, 1993). The California Current is one of three currents that make up the California Current System. The other two currents are the Davidson Current and the California Undercurrent (Hickey, 1998).

The California Current is a transition environment between subarctic and subtropical water masses and the freshwater inputs from the land. It is an “open” system, in which physical and biological properties vary with current fluctuations. The California Current is comprised of a branch of the Subarctic Current in the North Pacific, which surfaces in the summer along the west coast of the continent. When upwelling subsides in the fall, the northward-flowing California Undercurrent surfaces, sometimes called the Davidson Current, and carries warm equatorial water inshore (Bottom et al., 1993). During the spring and summer the equatorward surface flow prevails as equatorward winds prevail. It is associated with strong coastal upwelling, lowering sea surface temperatures along the coast (Strub et al., 1991).

B. PURPOSE

The purpose to this project is to compare the computed Geostrophic Currents calculated from data gathered from the 20 separate CTD casts with the currents measured by the Acoustic Doppler Current Profiler (ADCP) data. This data will then be compared to real time satellite data taken on the 8th of December, 2000 by the TOPEX/ERS-2 satellite. Specifically, the collected data will be compared to the sea surface height anomaly.

C. DATA AND PROCEDURES

1. Data Collection

The data collected by the CTD and ADCP was done along the CALCOFI Line 67 onboard the R/V Point Sur. The actual cruise that I was embarked was from 05 Feb through 08 Feb 2001, however due to high winds and rough seas I was forced to use a data set from December 2000. The actual date of the cruise was not supplied at the time when I began working on the data set, however an estimation was made that it was sometime at the end of the first week of December. The ship's track and the location where each CTD cast took place are displayed in Figure 1. With each CTD cast conductivity (which provided salinity), temperature and pressure was measured to a pressure of 1000 dbars, or 1000 meters. The vessel mounted ADCP measured currents along the line of the ship's course. Once processed the data plotted as North/South and East/West components and had to be rotated approximately 30° to correspond to actual across line and along line velocities.

2. Calculations

Calculations to determine Geostrophic Currents were made from the CTD data with MATLAB using Commonwealth Scientific and Industrial Research Organization (CSIRO) seawater programs. The MATLAB code for plotting of both the CTD data and the ADCP data are contained in Appendix 1.   As stated in Pond and Pickard, 1983, Geostrophic velocity is calculated as such:

$$(-1/\rho)\ (\partial p/\partial x) = f v$$

$$\therefore v = (-1/f\rho)\ (\partial p/\partial x)$$

with variable defined as:

ρ = density,

$f = 2\Omega\sin\phi$

$\Omega = 7.292\text{ e-}5\ s^{-1}$

ϕ = latitude

$\partial p/\partial x$ = pressure gradient between CTD casts

$$\Delta D = \int_0^z \delta dp$$

where

$\delta = 1/\rho$, specific volume anomaly

z = reference level, otherwise none as level of no motion (1000dbar)

$\partial x = \Delta x$, distance between CTD casts.

Therefore:

$$v = \frac{\Delta D}{2\Omega\sin\phi\Delta x}.$$

This calculates Geostrophic velocity 90° to the line, which is in line with the adjusted (rotated 30°) “across line” ADCP velocities.

D. RESULTS AND DISCUSSION

1. Synoptic Situation

As illustrated by TOPEX/ERS-2 satellite imagery in Figure 2, the sea surface height anomaly for 8 December 2000 shows two distinct features and a third on the very edge of the 35° Latitude. First is a high in the southwest portion of the image. The second is a low (≈ -1) centered at about 35°N 124°W. The third is the very edge of a higher elevation sea surface height anomaly to the west of the low. To maintain geostrophic balance the flow around these features are anticyclonic around the high and cyclonic around the low, although the flow may be weak around the low due to small surface height anomalies. This would result in equatorward flow between the high and low and also on the inside the high in the southwest portion of the image. The surface equatorward flow is much weaker during this period than during the summer time when upwelling is evident.

The T-S diagram in Figure 3 indicates that there is mixing at depth. More specifically the cold arctic component of the California Current is mixing with the more saline surface waters off the coast of California which is causing convective overturning and the heavier water to sink and continue to move equatorward. The warmer, less saline waters at the surface show much more salinity variation with a spread of about 1 part per thousand at its widest area.

2. Comparisons

a. Sea Surface Height Anomaly vs. ADCP currents

The ADCP "across line" velocity (Figure 4) corresponds well with the satellite depicted sea surface height anomaly showing weak poleward flow (positive values) in the same location as the low and strong equatorward flow (negative vales) in the areas of the highs. Also shown in the "across line" velocity is a stronger sub-surface poleward flow which would correspond to the California Undercurrent, which due to the time of year (winter) is getting closer to the surface.

The ADCP "along line" velocity (Figure 5) shows entirely positive values which corresponds to onshore flow. This is consistent with what is shown in the sea surface height anomaly. In the satellite image there are no height contours parallel to the coastline tightly packed which would indicate upwelling. This would also lead one to believe that there is onshore flow.

b. Sea Surface Height Anomaly vs. CTD data

Figures 6 and 7 display temperature and salinity sections, respectively, of the CTD data. Easily seen in both figures is a feature at the surface in the western portion with high temperatures and low salinities. Also, as expected with onshore flow, shown in both figures is evidence of downwelling. This is more evident in the temperature section. Also noted that in the sections there is mixing occurring which is evident by the uneven contours in the water column.

The temperature and salinity parameters are combined within MATLAB using the CSIRO seawater programs, to produce the density anomaly (Figure 8). The resulting figure looks incorrect at first glance, but the high density anomalies correspond to a lower temperature and higher salinity. The figure shows a high density anomaly between 100 and 200 dbars between 123°W and 124.5°W. This corresponds to a low in the sea surface height anomaly. To the west at the surface is a low in density anomaly, which would correspond to a high in the sea surface height anomaly. The fluctuations seen in the temperature and salinity plots are also seen here, although mainly in the upper layers.

c. CTD calculated geostrophic currents vs. ADCP currents

Calculated geostrophic velocities for line 67 are shown in Figure 9. The velocities are calculated and plotted down to 1000 dbar. The majority of the fluctuation of velocities is above 400 dbars with alternating poleward and equatorward flow. At depths there is very little variation in velocities and the flow is entirely equatorward. The upper portion of the plot is shown in Figure 10 for ease of comparison between the computed geostrophic velocities and the ADCP data. As shown the ADCP has similar equatorward flow in the western section, however the equatorward flow at approximately 123°W doesn't go below 100 dbars while in the computed geostrophic velocity plot has the flow going much deeper. The same is consistent with poleward flow off shore, however along shore the comparison is similar.

E. DISSCUSSION AND CONCLUSIONS

The TOPEX/ERS-2 imagery, ADCP currents and CTD data show a high correlation as it has in past comparisons of data along the same CALCOFI Line 67. The high sea surface anomaly was closely mirrored in the ADCP currents and the CTD data, especially the temperature and salinity plots. When comparing the geostrophic currents, computed from CTD data, with the ADCP currents the agreement was limited to the upper 100 dbars. This was primarily due to the complex nature of the water column.

The California Current defined by Bakun in the beginning of the paper as an equatorward flowing current was not observed, but rather was a mix of equatorward and poleward flow. The portion of Bakun's definition, which describes the California

Current as one that contains meanders, filaments and eddies, was evident. The California Undercurrent was evident along the coast in the ADCP data and the computed geostrophic velocities. The lack of Coastal Upwelling displayed in both the Temperature and Salinity plots is consistent not only with the TOPEX imagery, but also the Temperature, Salinity, ADCP, and computed geostrophic velocities as the poleward flow of the California Undercurrent reached the surface.

Overall, several components of the California Current System were evident in this study. Not only the equatorward flow of the California Current, but also a surface Davidson current with poleward flow.

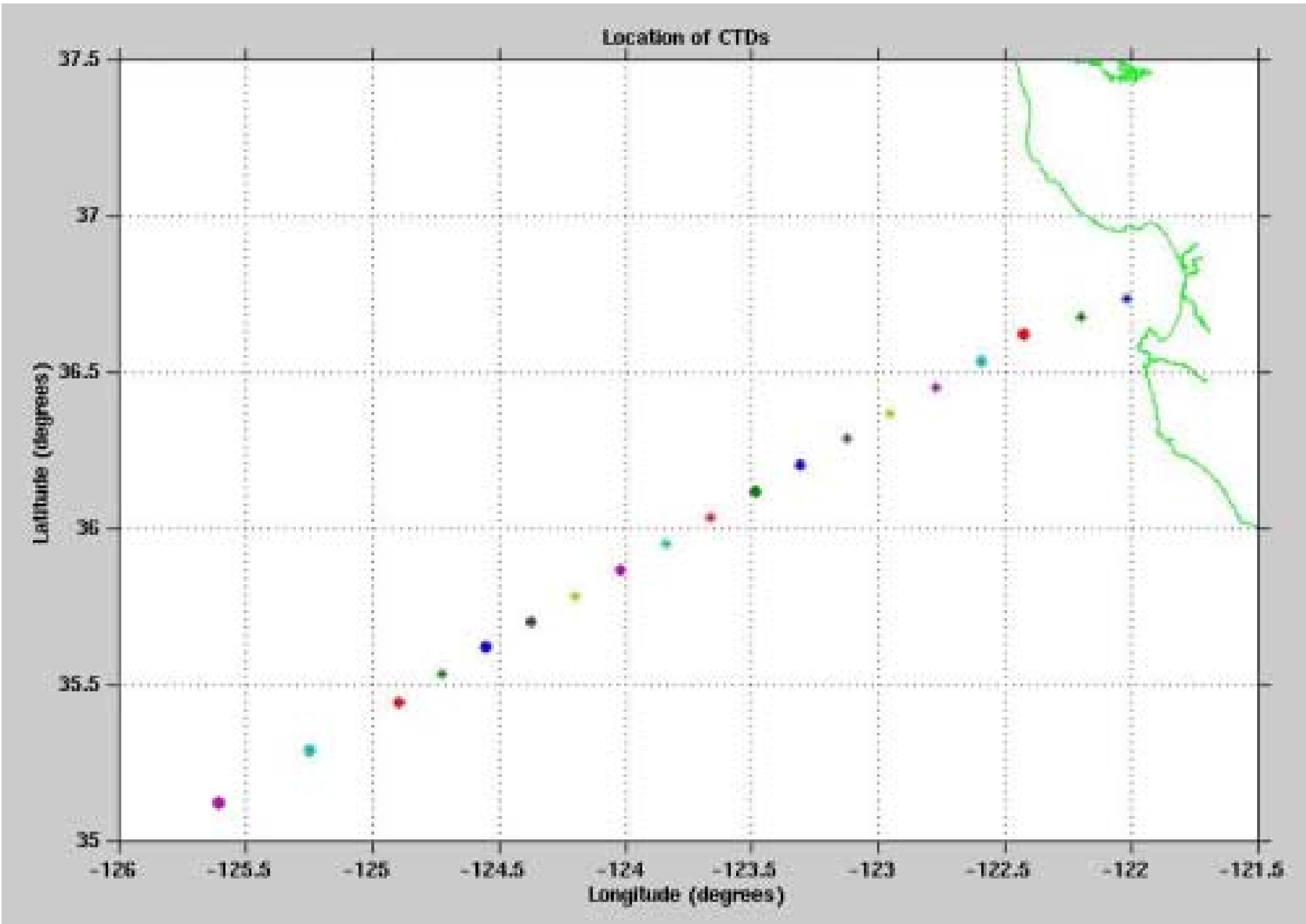

Location of CTDs
37.5
37
36.5
36
35.5
35
Latitude (degrees)
-126
-125.5
-125
-124.5
-124
-123.5
-123
-122.5
-122
-121.5
Longitude (degrees)

Figure 1.

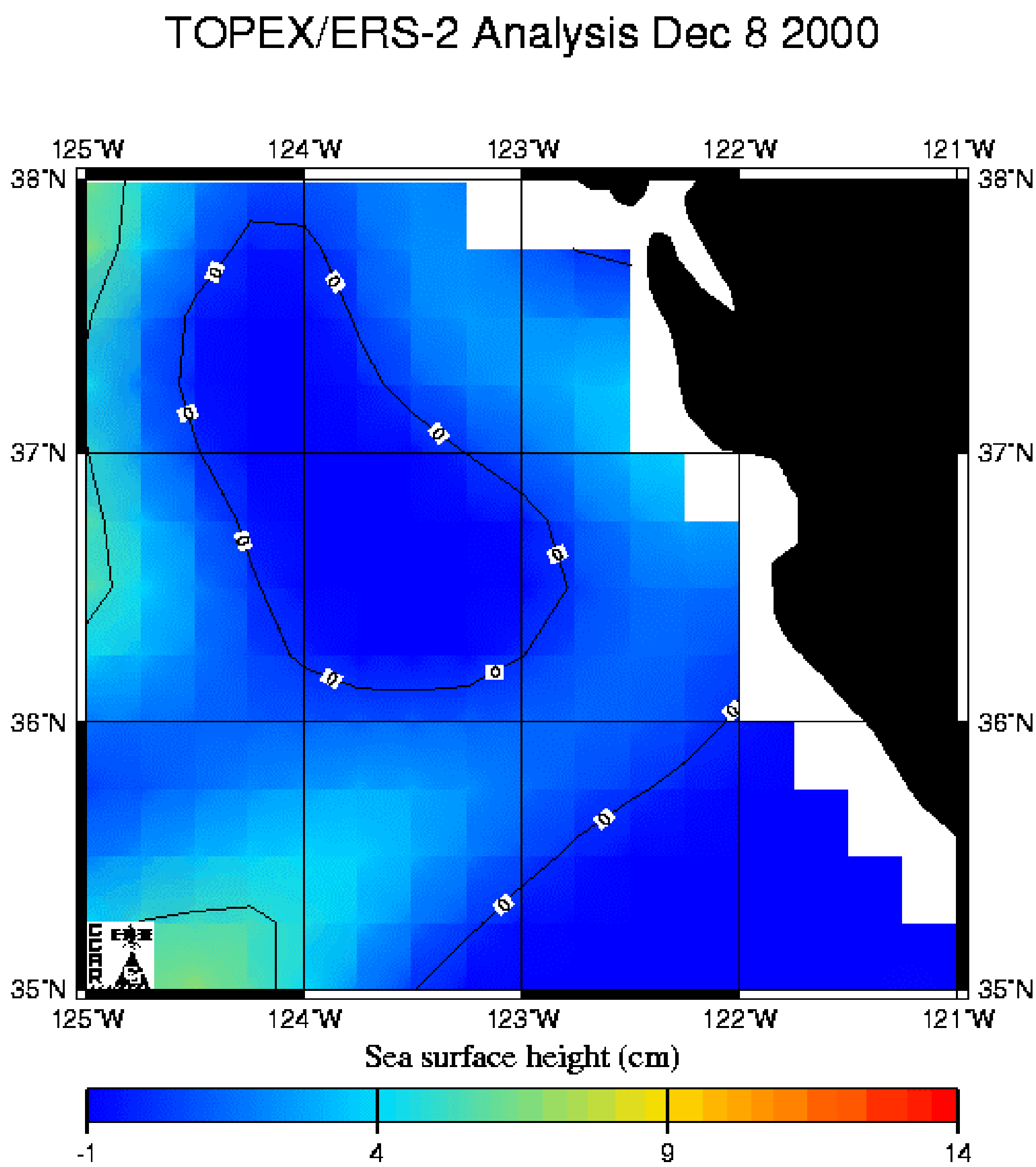

TOPEX/ERS-2 Analysis Dec 8 2000
125°W
124°W
123°W
122°W
121°W
38°N
37°N
36°N
35°N
0
Sea surface height (cm)
-1
4
9
14

Figure 2.

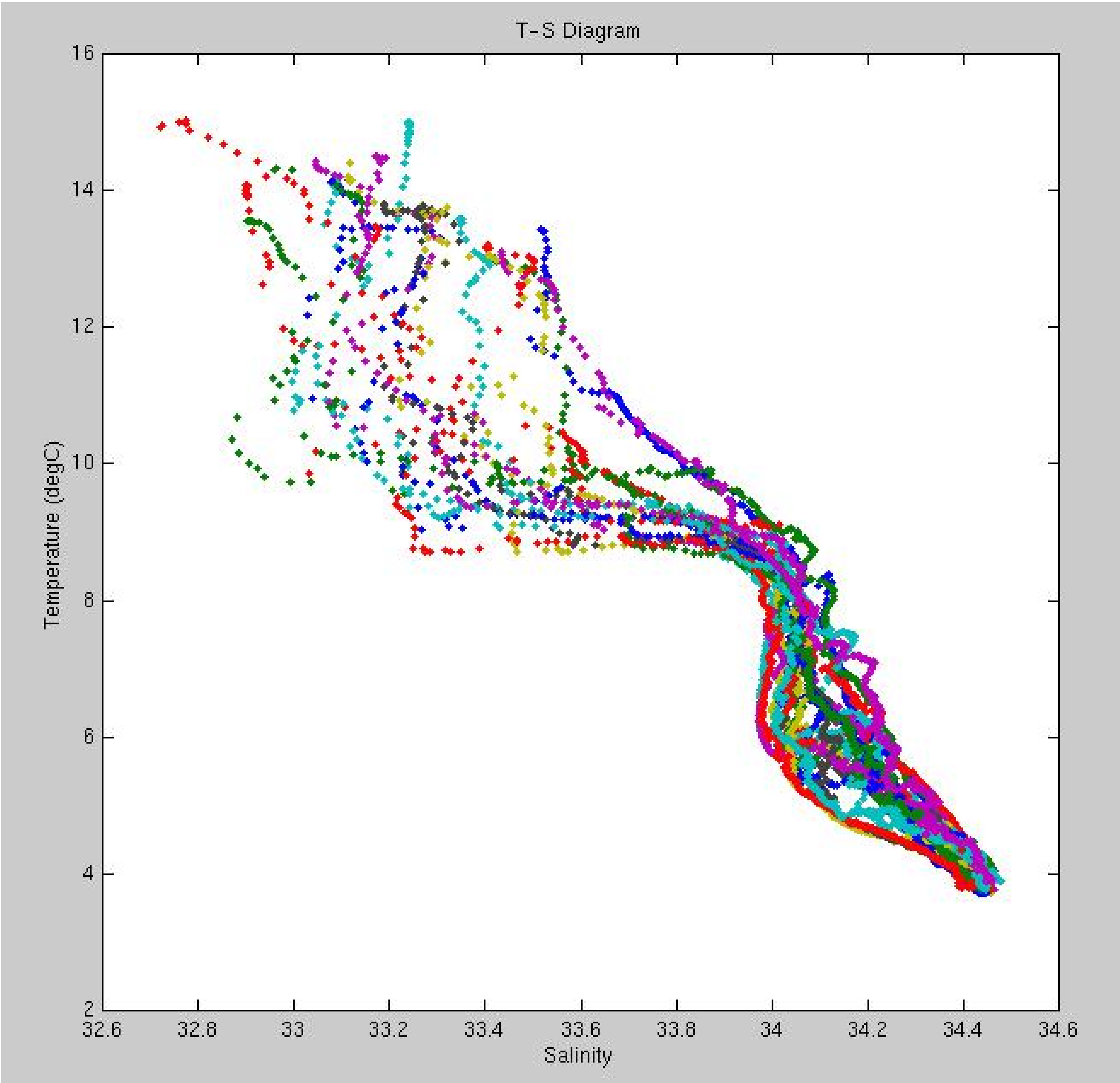

T-S Diagram
16
14
12
10
8
6
4
2
Temperature (degC)
32.6
32.8
33
33.2
33.4
33.6
33.8
34
34.2
34.4
34.6
Salinity

Figure 3.

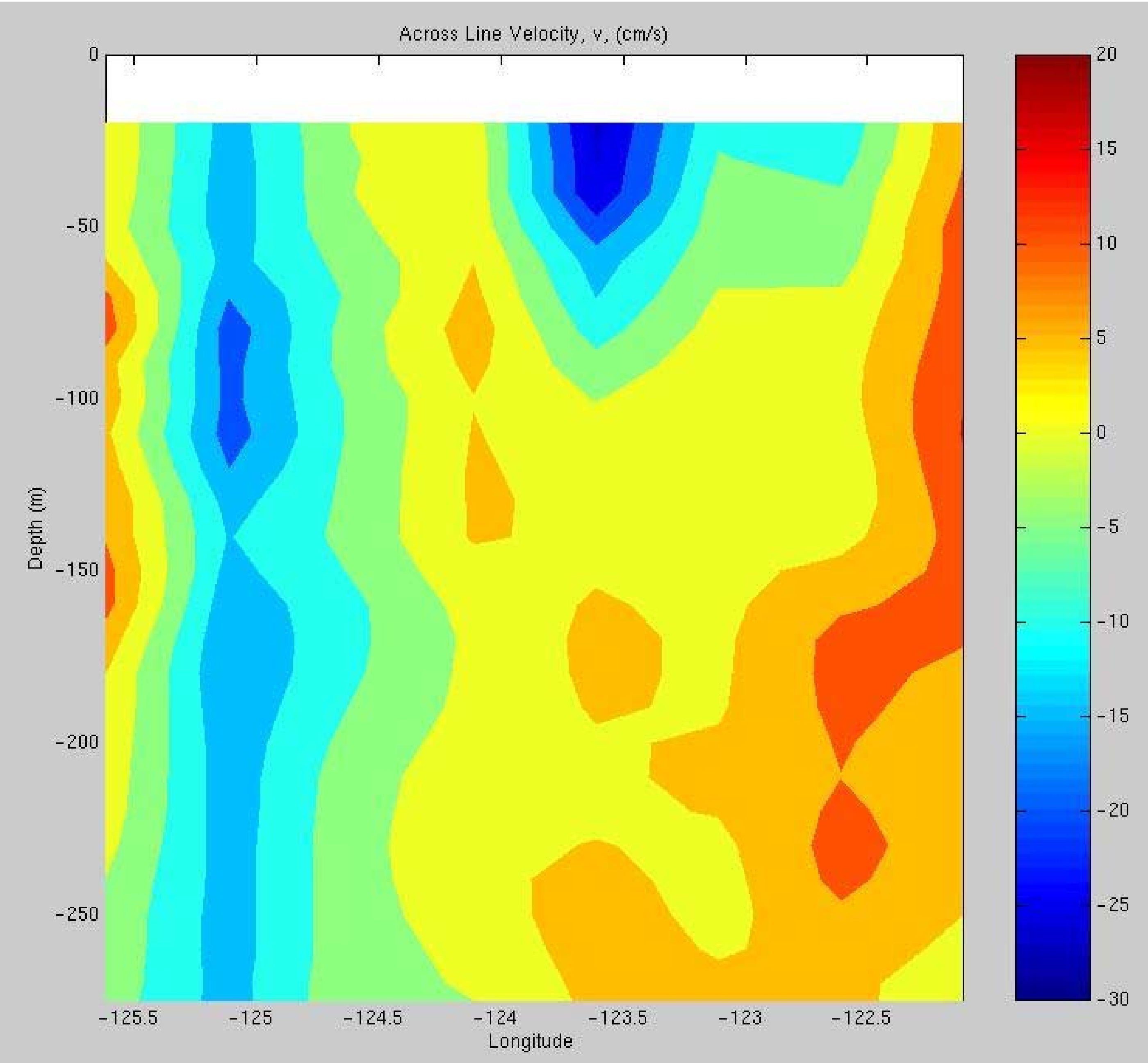

Across Line Velocity, v, (cm/s)
Depth (m)
Longitude
0
-50
-100
-150
-200
-250
-125.5
-125
-124.5
-124
-123.5
-123
-122.5
20
15
10
5
0
-5
-10
-15
-20
-25
-30

Figure 4.

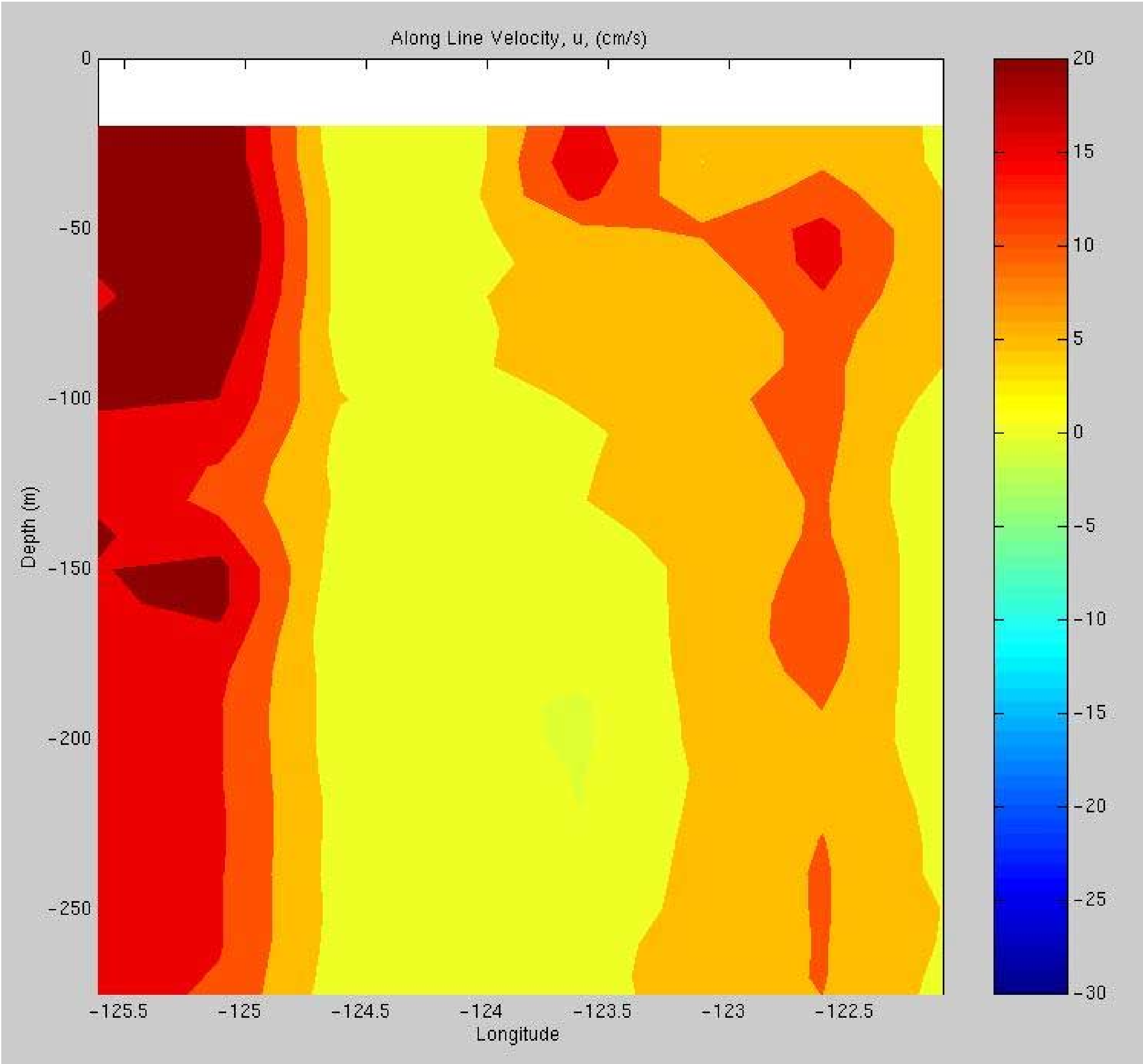

Along Line Velocity, u, (cm/s)
Depth (m)
Longitude
0
-50
-100
-150
-200
-250
-125.5
-125
-124.5
-124
-123.5
-123
-122.5
20
15
10
5
0
-5
-10
-15
-20
-25
-30

Figure 5.

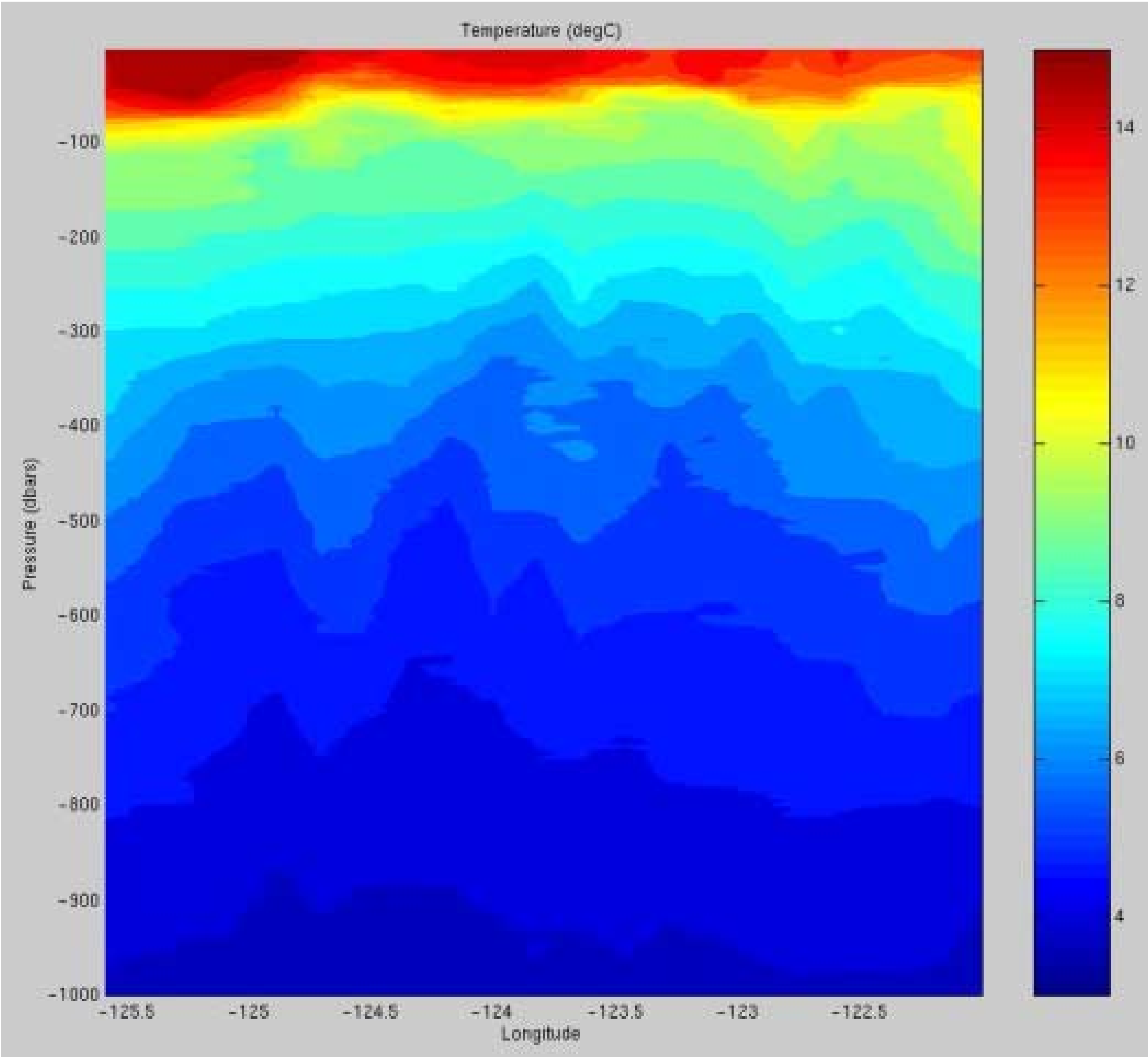
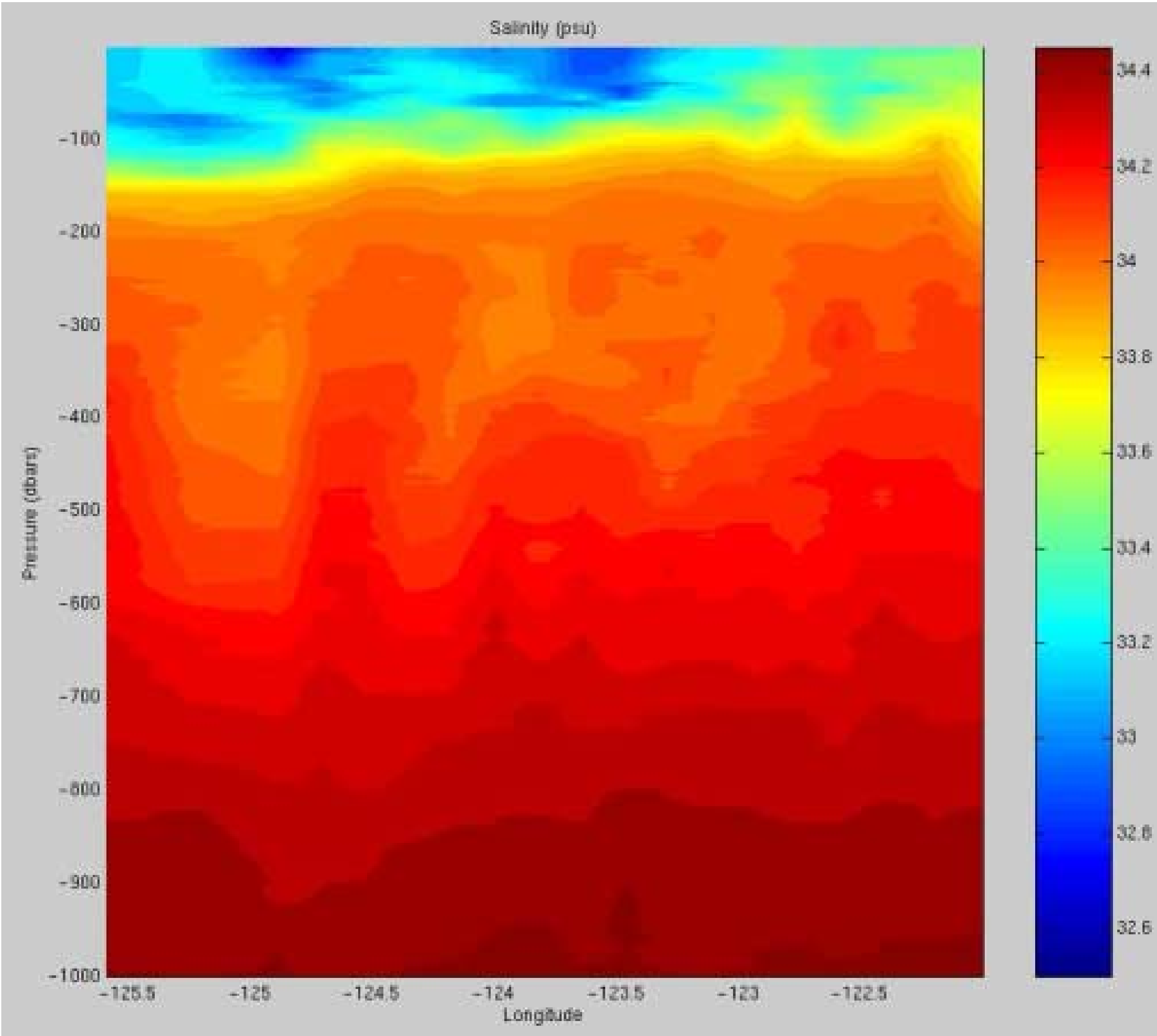

Temperature (degC)
Pressure (dbars)
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-125.5
-125
-124.5
-124
-123.5
-123
-122.5
Longitude
14
12
10
8
6
4

Figure 6.



Salinity (psu)
Pressure (dbars)
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-125.5
-125
-124.5
-124
-123.5
-123
-122.5
Longitude
34.4
34.2
34
33.8
33.6
33.4
33.2
33
32.8
32.6

Figure 7.

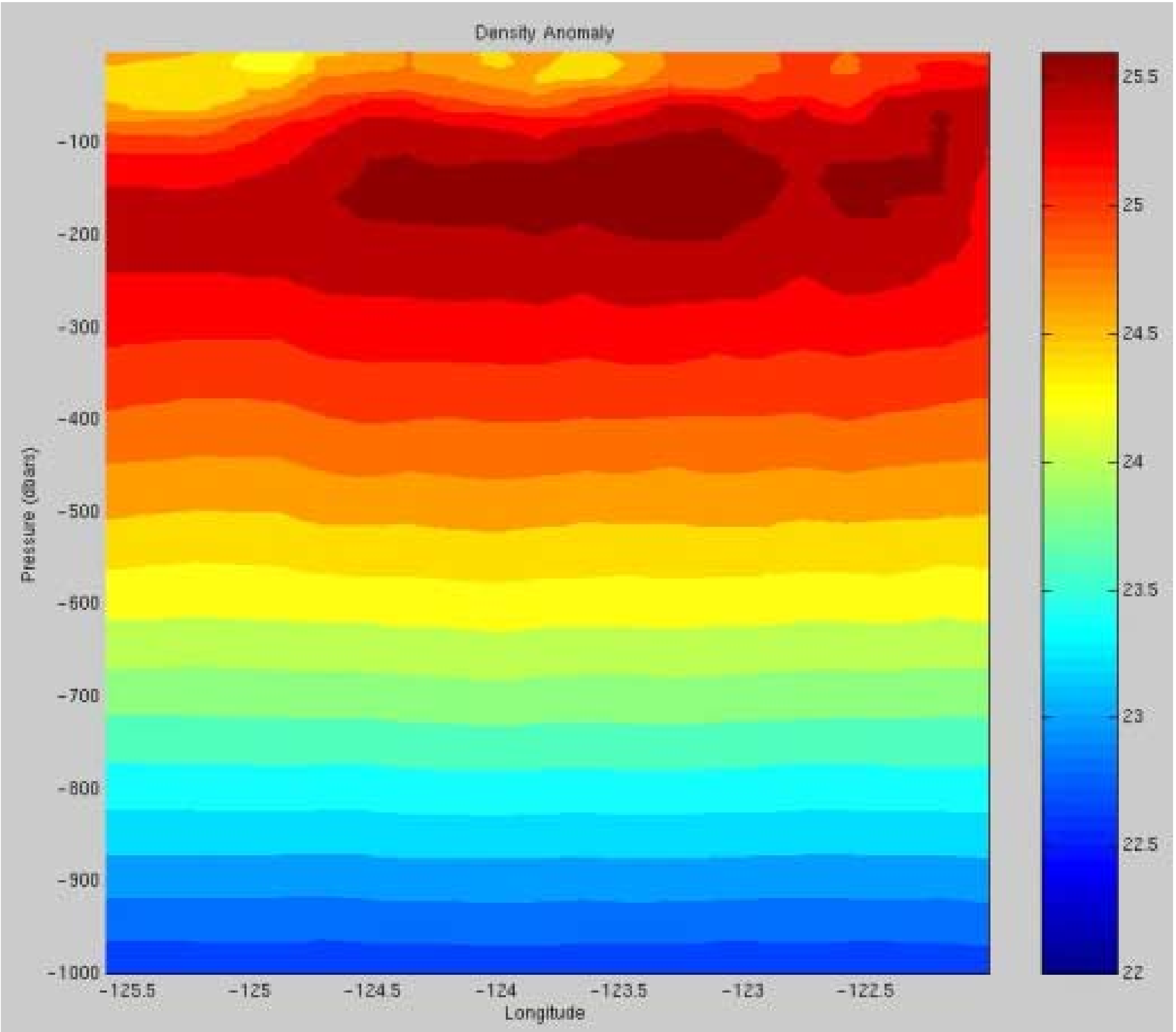

Density Anomaly
Pressure (dBars)
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-125.5
-125
-124.5
-124
-123.5
-123
-122.5
Longitude
25.5
25
24.5
24
23.5
23
22.5
22

Figure 8.

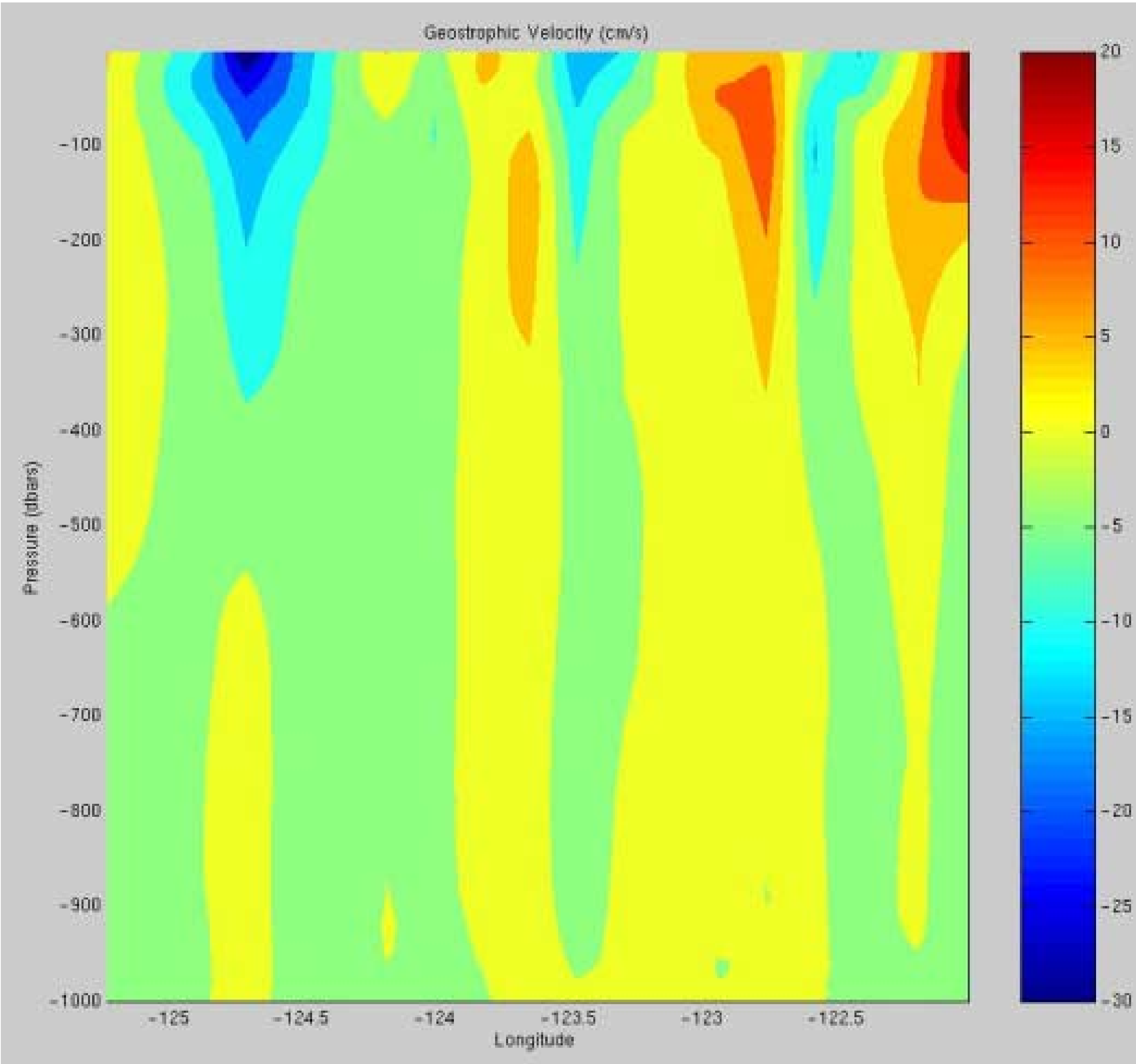

Geostrophic Velocity (cm/s)
Pressure (dbars)
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-125
-124.5
-124
-123.5
-123
-122.5
Longitude
20
15
10
5
0
-5
-10
-15
-20
-25
-30

Figure 9.

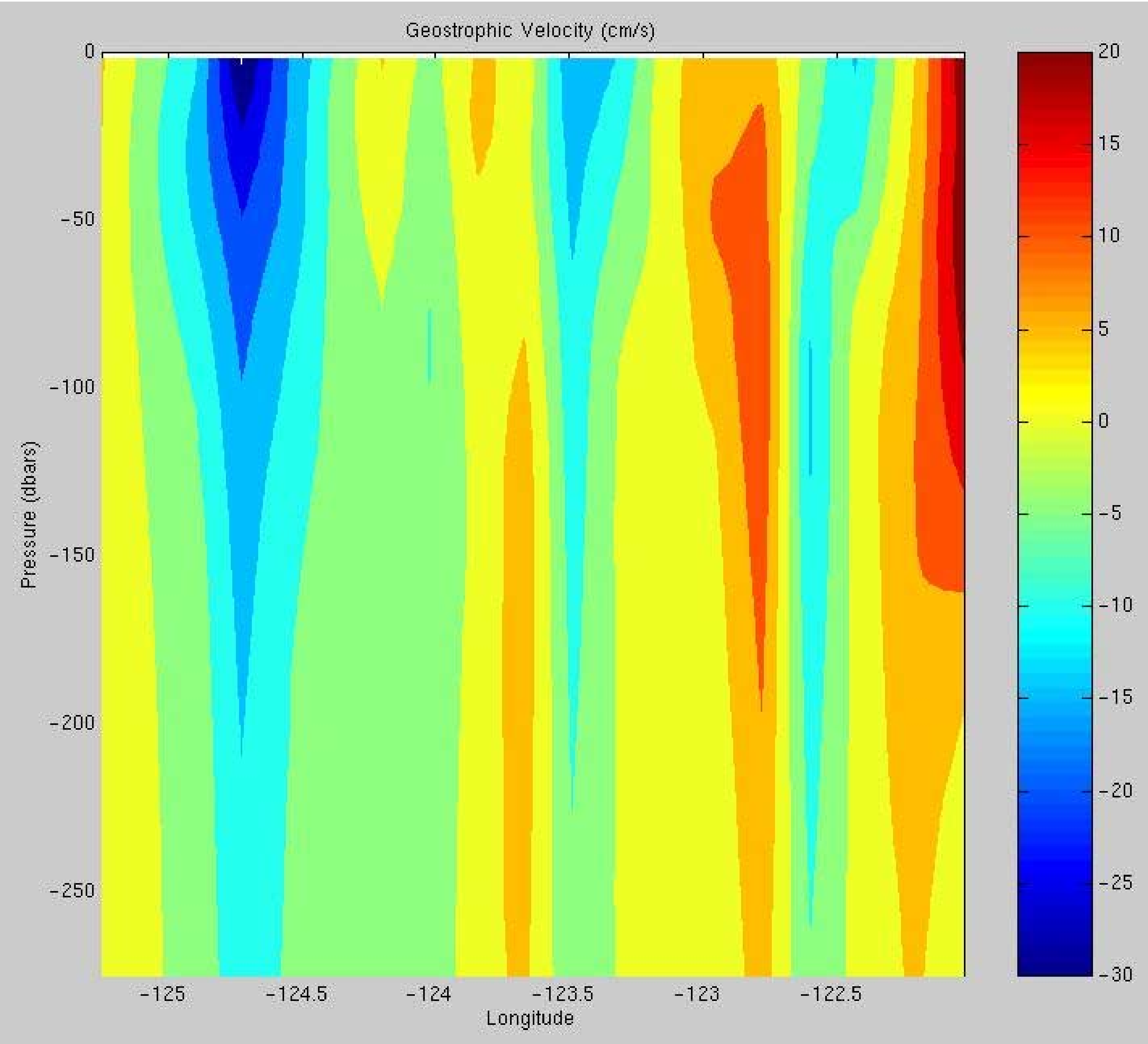

Geostrophic Velocity (cm/s)
Pressure (dbars)
0
-50
-100
-150
-200
-250
-125
-124.5
-124
-123.5
-123
-122.5
Longitude
20
15
10
5
0
-5
-10
-15
-20
-25
-30

Figure 10.

Appendix 1:

```
% ADCP
% OC3570
% Line 67 Data
% This program loads ADCP data and plots the across and along line
velocities
% Created:  Barbra Dubsky 30 August 2000
% Modified:  David Blencoe 10 March 2000

clear;

% Interactively load adcp data
fname=uigetfile('/tmp_mnt/host/a6/dgblenco/oc3570/*.*','Select file');
dat=load(['/tmp_mnt/host/a6/dgblenco/oc3570/',fname]);
long=dat(:,1)-360;
depth=dat(:,2);
u=dat(:,3);
v=dat(:,4);

% Meshgrid and griddata functions
l=min(long):.5:max(long);
d=min(depth):10:0;
[nl,nd]=meshgrid(l,d);
[nlon,nz,nu]=griddata(long,depth,u,nl,nd);
[nlon,nz,nv]=griddata(long,depth,v,nl,nd);

% Plot the two components
figure;
contlevs=[-30:5:21];
csl=contourf(nlon,nz,nu,contlevs);
caxis([-30 20]);
colorbar;
title('Along Line Velocity, u, (cm/s)');
xlabel('Longitude');
ylabel('Depth (m)');
axis([-inf inf -275 0]);
shading flat;
figure;
contlevs=[-30:5:21];
cs2=contourf(nlon,nz,nv,contlevs);
caxis([-30 20]);
colorbar;
title('Across Line Velocity, v, (cm/s)');
xlabel('Longitude');
ylabel('Depth (m)');
axis([-inf inf -275 0]);
shading flat;
```

```
% Geostrophic Velocity
%
% Line 67 data 00Dec
% Program provides geostrophic velocities using CSIRO Seawater programs
and
% plots geostrophic velicities, temperatures, salinity and density
anomalies.
%
% Created: Barbra Dubsky 30 Aug 2000
% Modified: David Blencoe 09 March 2001

callstart;
n=0;
for m=1:19            %Input 19 ctd files and load

fname=uigetfile('/tmp_mnt/host/a6/dgblenco/oc3570/data_files/*.dat','Se
lect File');
   disp(['Current File is 'fname])
   dat=load(['/tmp_mnt/host/a6/dgblenco/oc3570/data_files/',fname]);
   [nrows,ncols]=size(dat);
   if nrows>499;
      n=n+1;
      eval(['ctd',num2str(n),'=dat;']);
   end
end


lat=[];
long=[];
pres=[];
temp=[];
sal=[];

b=500;                %Reference Level 1000 dbar, @ row 500

% Creat lat, long, pressure, temp and salinity matrices
for l=1:n;
   eval(['a=ctd',num2str(l),';']);
   c=a(1:500,1:12);
   lat=[lat c(:,3)];
   long=[long, c(:,4)];
   pres=[pres, c(:,5)];
   temp=[temp, c(:,6)];
   sal=[sal, c(:,8)];
end

% Calculate geostrophic velocity
apres=pres(:,1);
avelat=mean(lat);
avelong=mean(long);
gpa=sw_gpan(sal,temp,apres);
gvel=sw_gvel(gpa,avelat,avelong);

% Correct for reference level 1000 dbar
along=avelong(1:18)';
ref_level=500;
vel=[];
```

```
for icol=1:n-1;
   vel(:,icol)=gvel(:,icol)-gvel(ref_level,icol);
end
velcm=vel*100;

% Plot geostrophic velocity for entire range and equivalent range to
ADCP plots
contlevs=[-30:5:21];
figure;
cs=contourf(along,apres,velcm,contlevs);
caxis([-30 20]);
colorbar;
shading flat;
title('Geostrophic Velocity (cm/s)');
xlabel('Longitude');
ylabel('Pressure (dbars)');

figure;
contourf(along,apres,velcm,contlevs);
caxis([-30 20]);
axis([-inf inf -275 0]);
colorbar;
shading flat;
title('Geostrophic Velocity (cm/s)');
xlabel('Longitude');
ylabel('Pressure (dbars)');

% Plot Temperature
figure;
conttemp=[3:.5:17];
contourf(avelong',apres,temp,conttemp);
title('Temperature (degC)');
xlabel('Longitude');
ylabel('Pressure (dbars)');
colorbar
shading flat

% Plot Salinity
figure;
contsal=[32.5:.05:34.5];
contourf(avelong',apres,sal,contsal);
title('Salinity (psu)');
xlabel('Longitude');
ylabel('Pressure (dbars)');
colormap(jet(256));
colorbar;
shading flat;

% Calculate and plot Density Anomaly
dens=sw_dens(sal,temp,apres);
densanom=dens-1000;
figure
contden=[22:.2:27];
contourf(avelong',apres,densanom,contden);
title('Density Anomaly');
xlabel('Longitude');
ylabel('Pressure (dbars)');
```

```
axis ij;
colorbar;
shading flat;

% Plot Limited Density Anomaly Data
figure;
contden2=[24:.2:26];
contourf(avelong',apres,densanom,contden2);
title('Limited Density Anomaly');
xlabel('Longitude');
ylabel('Pressure (dbars)');
axis ij;
colorbar;
axis([-inf inf -275 0]);
shading flat;

% Plot track line and location of CTD's
figure;
wcoastplot([-126,-121.5],[35,37.5]);
hold on
plot(long,lat,'*');
grid;
title('Location of CTDs');

% Plot T-S diagram
figure;
plot(sal,temp,'.');
title('T-S Diagram');
xlabel('Salinity');
ylabel('Temperature (degC)');
axis square;
```

REFERENCES

Websites:

Colorado Center for Astrodynamics Research, “Global Near Real-Time Altimeter Data Viewer”. [http://www-ccar.colorado.edu/~realtime/global-real-time_ssh/] December 2000.

Large Marine Ecosystems of the World, “Large Marine Ecosystem #3”. [www.edc.uri.edu/lme/default.htm] March 19, 2001

Published Works:

Bakun, A, “The California Current, Benguela Current, and Southwestern Atlantic Shelf Ecosystems: A Comparative Approach to Identifying Factors Regulating Biomass Yields” in Large Marine Ecosystems of the World, pp. 199-221, 1993

Bottom, D. L.; Jones, K. K.; Rodgers, Jeffery D., and Brown R. F. “Research and Management in the Northern California Current Ecosystem” in Large Marine Ecosystems of the World, 1993

Hickey, B., “Coastal Oceanography of Western North America From the Tip of Baja California to Vancouver Island; Coastal Segment” in *The Sea*, Robinson, A. R., and Brink, K. H., pp 12947-12966, 1998.

MacCall, A. D., “Changes in the Biomass of the California Current Ecosystem” in Large Marine Ecosystems of the World, 1986.

Strub, P. T., Kosro, P. M., and Huyer, A., “The Nature of the Cold Filaments in the California Current System” Journal of Geophysical Research, Vol 96, No. C8, pp. 14,743-14,768, 1991.